LIGHTS ON

cultural heritage and museums!

Paula Menino Homem [Ed.]

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LIGHTS ON…

CULTURAL HERITAGE AND MUSEUMS!

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Towards a combined use of IR, UV and 3D-Imaging for the study of small inscribed and illuminated artefacts

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Abstract

When heritage objects are being transformed into digital representations, the loss of information is inevitable. The challenge lies in developing integrated systems able to minimize this loss and bring together as many different kinds of recordable characteristics as possible of one and the same object.

This contribution presents an approach that combines the detection of colour, surface shape and the reflective characteristics of surfaces by using a selection of IR, Red, Green, Blue and UV light spectra and applying them on 3D models. A multispectral, multi-directional, portable and dome-shaped recording tool has been developed to this end. With the associated software, virtual relighting and enhancements can be applied in an interactive manner based on the principles of photometric stereo: this allows alternating in real time between computations with IR, R, G, B and UV light spectra. Throughout the testing phases, this non-invasive registration and documentation technique has been applied to monitor and study a vast number of heritage objects, varying from 19th c. BCE Egyptian inscribed clay figurines to medieval illuminations.

Keywords Multispectral imaging; Photometric stereo; Conservation; Documentation; Ancient inscriptions

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1. Introduction

"(…) *where our predecessors wanted to reproduce the original, if they could not have the original itself, we now try to improve the original*"

(Bülow-Jacobsen, 2011, p.2)

Multispectral imaging has proven its value and usefulness in particular for remote sensing, including earth observations, astronomy and planetary science, and was further applied in other fields, such as biology, medicine, chemistry, etc. In the early 1990s, it also entered the field of cultural heritage studies, especially as one of the main advantages lies in the non-invasive / non-destructive character of this technique. Hence it can be applied to all sorts of objects and materials, ranging from intact to extremely fragile and deteriorated surfaces, since sampling physical material is not required (Liang, 2012). Therefore, it is also used in the fields of art technical research, conservation science and archaeology, where the focus lies mainly on paintings, manuscripts and to a lesser extent on papyri and inscribed pottery sherds (ostraca). Applying the different spectra enables a precise examination and identification of colours and pigments, the visualisation of underlying features, and the identification of varying materials or surface conditions. A shortcoming of these approaches, however, is the absence of geometrical data.

The aim and challenge of the proposed hardware-software solution is the development of a method that can capture, register, and visualize the physical three-dimensionality of objects together with the visible and concealed / faded pigments on their surface. Information is inevitably lost when heritage objects are being transformed into digital representations. Integrated systems, able to minimize this loss and bring together as many different kinds of recordable characteristics as possible of an object, are therefore desired. This paper presents an approach that combines the detection of colour, surface shape and the reflective characteristics of surfaces by overlaying the geometrical datasets with a selection of IR, Red, Green, Blue and UV light spectra. This leads to a user-friendly and cost-effective methodology, applicable to a wide variety of heritage objects.

Within the framework of the research projects RICH (University of Leuven)[4] and EES (Royal Museums of Art and History, Brussels)[5], a multispectral, multi-directional, portable and dome-shaped acquisition system has been developed in collaboration with the ESAT-VISICS research group of the University of Leuven. With the associated software solution, virtual relighting and enhancements can be applied in a real-time, interactive manner. The dome extracts genuine 3D and shading information based on the principles of photometric stereo. This innovative approach allows for instantaneous alternations between the computations in the IR, R, G, B and UV light spectra.

RICH

The RICH (Reflectance Imaging for Cultural Heritage) project has developed two imaging devices for research, study, and exploration of the physical characteristics of graphic materials produced in medieval and early modern times. The first tool – labelled 'Microdome' –

[4] Reflectance Imaging for Cultural Heritage (RICH) is a project from Illuminare (Centre for the Study of Medieval Art, KU Leuven), financed by the Hercules Foundation 2012-2015 (Flemish government) – Project AKUL/11/03, site: http://www.illuminare.be/rich_project.

[5] The Egyptian Execration Statuettes project (EES) is financed by the Brain-be Pioneer programme of the Belgian Science Policy Office-BELSPO (project BR/121/PI/EES): http://www.kmkg-mrah.be/conservation-ir-uv-and-3d-imaging-egyptian-execration-statuettes, and supported by the BELSPO Interuniversitary Attraction Poles Programme Greater Mesopotamia – Reconstruction of its Environment and History (GMREH) (Project IAP 7/14): www.greatermesopotamia.be.

consists of a hemispherical structure, with an overhead camera and white light LEDs regularly covering the dome's inside surface. Similarly, the second Microdome structure exhibits LEDs emitting in five different parts of the electromagnetic spectrum, ranging from ultraviolet over visible to infrared light. The development of this Multispectral (MS) Microdome enables multispectral imaging, expanding such non-destructive art-technical research into the realm of 3D modelling. The two Microdomes have shown their potential as instruments to analyse extremely small art technical features and monitor conservation treatments (Watteeuw et al., 2013; & 2014).

The main focus of the RICH research is on medieval manuscript illuminations, as these are unique artefacts drawn, written and illuminated with mineral and organic materials. Rarity and fragile conditions render manuscript illuminations difficult to access as they are mostly kept in secured library vaults. Imaging the characteristics of the undulating parchment, the pictorial layers and the laid gold reveals to scholars and conservators the 'hand', the techniques and the materials of the medieval book artists. The documentation of these characteristics with the white light and MS Microdomes is extremely useful as it can document and measure 1) the 3D surface structure of the parchment, 2) the sequence of the writing, 3) the underdrawing, 4) the preparation of the gilded layers, 5) the brushstrokes applying the different mineral and organic materials, and 6) the finishing of the pictorial touch with glazes and pen work. Besides supporting questions of attribution, changes and decay of the material characteristics can be monitored, supporting decision-making in the conservation protocol.

The high-quality, accurate results of both Microdomes can be visualized in a most versatile manner. All visualization modes are based on a single recording procedure, taking only a few minutes. For the synthesis of the virtual images a large number of filters and relighting options can be applied. They enable the detection of object surfaces even when difficult to access, the generation of 2D+ models, and the life-like or visually enhanced interaction with the recorded artefact.

EES

The Egyptian Execration Statuettes (EES) project aims to create multispectral 3D images of a series of fragile Egyptian objects of the RMAH collection in order to 1) ensure their sustainability by reducing future handling, and 2) facilitate their study by developing an efficient course of action to record details on their surface. The selected case study includes, more specifically, 104 “Execration figurines”, roughly modelled clay figures representing prisoners, dating back to the Middle Kingdom (c. 1900 BCE) (Posener, 1940). Their surface is covered with inscriptions in hieratic, an ancient Egyptian cursive writing system, enumerating enemies of the flourishing Egyptian empire. By listing foreign countries, tribes, rulers, and places, these objects are invaluable primary sources for our knowledge of the ancient political geography of the Near East. They are internationally recognised as Prime Cultural Heritage Artefacts. Unfortunately, the study of this type of collection is hindered by their poor state of conservation (being made of unbaked rough clay), as handling and any intervention carried out on them can result in considerable material losses. The second major obstacle for researchers is the partial preservation of the ink traces and their poor visibility in white light.

The aim of the EES project is to enhance the readability of the hieratic inscriptions on the execration figurines with UV and IR photography, all the while producing reliable 3D models and allowing scholars to examine the results in combination with the actual relief characteristics and properties of the physical object. As our Portable Light Dome systems – the white Microdome as well as the preceding Minidome (Willems et al., 2005) – have proven to be particularly suitable for the registration and visualisation of clay surfaces (Hameeuw and Willems, 2011; Boschloos et al., 2014; Hameeuw and Van Overmeire, 2014), the same approach was selected for this challenge. The newly developed interactive multispectral module offers the ability to search for the most optimal visualisation conditions while shifting between calculations based on the recordings with the different spectra. Subsequently, these tools will also be used to ensure the multispectral 3D digitalization of other fragile objects bearing inscriptions or pigments, such as ostraca, tablets, papyri, bowls, etc. (for a first result, see Van der Perre and Hameeuw, 2015).

2. Related works

Multispectral imaging is frequently used in (and shows excellent results for) the study of manuscripts and palimpsests (cfr. The Dead Sea Scrolls (Caine and Magen, 2011); The Archimedes Palimpsest (Easton et al., 2011); Medieval Palimpsest Manuscripts Project Göttingen (Albrecht, 2014); The Magna Carta Project (Dufy, 2015; Giacometti et al., 2012).

When it comes to using multispectral imaging for the documentation of archaeological objects, the focus lies mainly on papyri and ostraca, i.e. relatively flat objects containing inscriptions and/or drawings (Booras and Seely, 1999; Fisher and Kakoulli, 2006; Macfarlane et al*.,* 2011; Faigenbaum et al*.,* 2012; Sober et al*.,* 2014). In Egyptology, multispectral imaging has also been used for the documentation of wall paintings (Kotoula, 2012), inscriptions on mummy shrouds (Corcoran and Svoboda, 2012, pp.57-58) and mummy masks and portraits (Making the Mummies Talk (Mazza, 2015); the APPEAR Project (Anandan, 2015; Ganio et al., 2015; Shah, 2015). Apart from merely documenting objects, multispectral imaging has also been used for the identification of historical pigments (Dyer and Simpson, 2012; Cosentino, 2014). Whether there is an actual added value in using multispectral recordings, when simple infrared photography might offer equal results, has been the subject of scholarly discussion as well [The value of MS imaging is questioned by Bülow-Jacobsen (2008), while his statements are countered by Bay et al., 2010].

On the other hand, 3D imaging has been intensively used in the past years. Most satisfying results were reached for reconstructions of large architectural features, objects, paper and canvas documents (e.g. Remondino, 2011; Abate et al., 2014) and for the documentation of very small objects or for surfaces on which the smallest details matter, such as archaeological artefacts with cuneiform signs and seal impressions (Hameeuw and Willems, 2011). For art conservation, high magnification 3D in-focus microscopy with the HIROX 3D binocular has been explored for examining the surface layers in paintings by Van Eyck, Vermeer, Hals and Van Gogh (Boon, 2015).

Recently, photogrammetry and infrared techniques have been successfully combined (i.e. partly integrated) in the study of art and archaeological objects (Bennett, 2015; Keats Webb, 2015). Furthermore, in isolated test recordings, Reflectance Transformation Imaging (RTI) techniques were used in combination with the use of IR and UV spectra (Kotoula, 2012; 2015). Unfortunately, these cases cover only one aspect of the documentation process we are aiming at; the outcome is either a method providing information on the geometry of the recorded surface with a texture map based on visible light, IR or UV separately; or it consists of 2D representations based on a recording process with varying spectral wavelengths, whether or not moulded into an integrated interface.

The RICH and EES projects propose an innovative combination of these methods by adding a multispectral aspect to the previously developed Portable Light Dome system (PLD). This comprehensive approach interactively integrates computations based on recordings with visible white light, IR and UV, i.e. detecting texture maps and normal maps. It provides curators, conservators, researchers and other stakeholders with virtual artefacts for a broad range of historical and technical studies and will facilitate the management of the recorded objects.

3. General setup

The starting point was the initial hard- and software infrastructure of the Portable Light Dome system (Willems et al., 2005), which is continually evolving into an effective tool for studying, monitoring and understanding the materials and surface characteristics of a wide variety of heritage objects (Hameeuw and Willems, 2011; Watteeuw et al., 2013)[6]. The initial outcome of the PLD system was the `Minidome' with 260 white light (VIS) LED emitters (Ø80x80mm); transformed within the RICH project into a smaller Microdome with 228 white LEDs (Ø30x30mm). The joint multispectral efforts of RICH and EES resulted in a MS Microdome (finished) and a larger MS Minidome (under development).

[6] The PLD itself was a follow-up result of an initially fixed photometric stereo setup that came with several degrees of freedom in camera motion and was used for the study of textured surfaces.

Based on the experiences gained throughout the development stages and thanks to the joint input by heritage specialists, archaeologists, art historians, epigraphists, photography experts and electrical engineers, the multispectral component could be incorporated into the existing PLD system. Within the RICH project, the white light Minidome was specifically adapted towards documentary heritage objects such as manuscripts and books. To allow for the imaging of the interior, fragile bookbinding of manuscripts, a segment of the Microdome can be taken off. A rigid structure on top of the dome hosts the high-resolution sensor (28.8 million pixels) and lens combination (FIG. 1). It also allows the Microdome to fit onto a Conservation Copy Stand (developed by Manfred Mayer, Graz) as well as a standard tripod or studio stand. Therefore, the Microdome can be used in many desired positions or angles.

4. Choices

4.1 Sensor

The sensor of choice is the Allied Vision Prosilica GX 6600 (Allied Vision, 2015). It is a high-resolution 35mm machine vision CCD sensor (6576 × 4384 pixels) enabling vibration free capture through the digital shutter, the latter as opposed to a manual shutter. The resolution of the sensor allows for the capture of small details at high magnification factors. The sensor can be delivered in both a colour and black and white version. The black and white sensor is sensitive in the UV, visible and IR spectra. The colour version has been fitted into the white light Microdome, the black and white version into the multispectral Microdome.

FIG. 1 - The construction of the Microdome with the rigid superstructure to fit the camera and lens combination. The structure can be mounted on standard photographic equipment such as a tripod or studio stand, allowing the user to position the Microdome in the desired angle. The MS Microdome has the exact same setup. (©RICH project, KU Leuven).

4.2 Lens

Ultraviolet and infrared light have a different plane of focus than visible light, an effect also known as 'focus shift'. The Portable Light Dome uses all the LEDs, with their different light spectra, within one and the same recording sequence. When one wants to ensure stability throughout the image capturing sequence, it is virtually impossible to refocus the lens for optimal sharpness without disturbing it. The option of decreasing lens aperture (Nikon AF-D 60mm F/2.8 macro) to increase the depth of field proved, after testing, unsatisfactory with close-up imaging. The depth of field was also limited due to the use of the large 35mm sensor, compared to smaller sensor imagers that have a much bigger depth of field.

To counter the focus shift the CoastalOpt UV-VIS-IR 60mm Apo Macro lens (Jenoptik inc, 2015) was selected and acquired. Five of its 10 lens elements are made of calcium fluoride, enabling true apochromatic performance between 315 and 1100 nm.

4.3 Light sources

LEDs were selected as light source. A total of 228 LEDs were evenly distributed across the inside of the Microdome. The white light Microdome was fitted with a high-powered neutral white LED, with a colour temperature of 4000° K. The MS Microdome was fitted with five different spectra. The selection of the bands was partly based on the spectra used within the Archimedes Palimpsest project (Archimedes Palimpsest, 2010) and adopted towards the particularities of the PLD set-up. Since the colour and the multispectral PLD versions were planned in a way that most of their structure could be shared, the white light and multispectral LEDs required to have the same specifications such as size, construction, drive current, etc. They also had to be available in sufficient quantities. The choice fell on the LED Engin LZ1 product family (LED Engin, 2015). The five spectra selected are: UV 365 nm, Blue 465 nm, Green 523 nm, Red 623 nm and IR 850nm, each different types again evenly distributed across the dome. Their numbers vary from 44 to 48 LEDs per type (FIG. 2 and 3). A simulation of different distribution patterns obtained through an even permutation of 5 different LEDs yielded the patterns in FIG. 2. The most even and symmetric distribution was selected and implemented (FIG. 3). The arrangement of the LEDs enabled the removal of a segment of the dome without sacrificing the overall distribution.

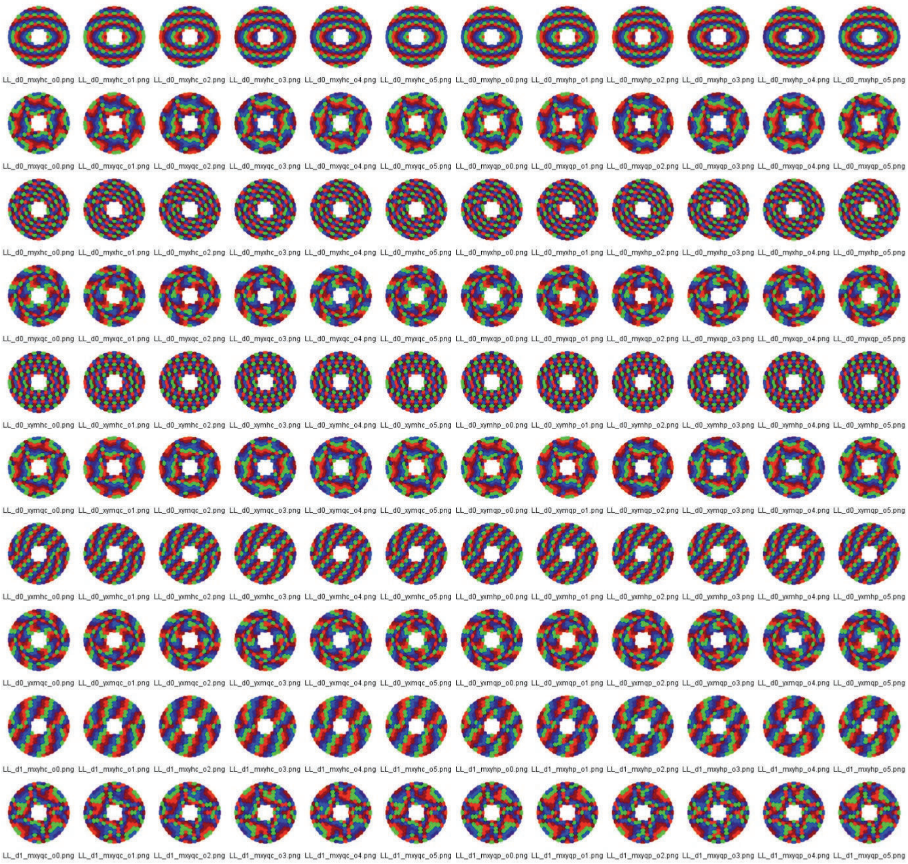

FIG. 2 - A choice of different permutations for the distribution of the 5 different LED emitters on the multispectral Microdome. (© RICH project & ESAT-VISICS, KU Leuven).

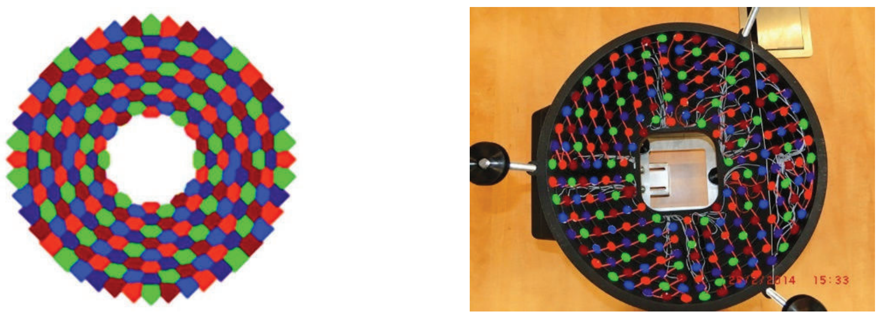

FIG. 3 - The selected distribution of the 5 different spectra implied on the inside of the Microdome. (© RICH project & ESAT-VISICS, KU Leuven).

4.4 Software

The results of the software package can be uploaded in a custom-made interactive (2D+) environment, the PLD viewer. The underlying methodology to determine the normal and surface information is based on the principles of Photometric Stereo (Woodham, 1980; Horn, 1986, Chapter 10-11; Verbiest and Van Gool, 2008). As opposed to Polynomial Texture Mapping (Malzbender et al., 2001; Earl et al., 2010), which tries to fit the observations with a mathematical function or description in order to mimic the appearance in a kind of make-believe visualization, Photometric Stereo methods recover the actual 3D shape and albedo of a surface using multiple images in which the viewpoint is fixed and only the lighting directions vary. The technique is based on the fact that the amount of light reflected by a surface depends on the orientation of the surface in relation to the viewpoint of the camera and the position of the light source. The dome-shaped devices that we developed, consist of a single, down-looking camera on top of a hemisphere with LED light sources covering the inside surface. With this setup, the position of the object and the camera can be kept constant, while varying the position and angle of the light source by subsequently activating the different LEDs. Traditionally this method has only been verified with LED light sources of the same type, by default white light. Our starting point for the proposed algorithm is the existing CPU-only implementation (initiated in Willems *et al*., 2005; see also Watteeuw et al., 2013).

The recovered results allow for both photorealistic and non-photorealistic virtual renderings of the scanned surfaces. To represent the geometry and the colour effectively, the currently implemented algorithm produces three output images: a normal image, an albedo image and an ambient image (FIG. 4). The normal image is a two-valued representation of the geometric details of the digitized object. It contains the surface orientation for each pixel and thus yields information on the overall physical shape of the object through integration of the pixel-wise normals.

FIG. 4 - The normal (left), albedo (center) and ambient (right) result images for the scan of a moth. (© ESAT-VISICS, KU Leuven).

The albedo image contains the diffuse reflection coefficient for each pixel, providing information on the optical characteristics of the object's surface (Coakley, 2003). The amount of energy that is reflected by a surface is determined by the reflectivity of that surface, called the albedo. A high albedo means the surface reflects the majority of the radiation that hits it and absorbs the rest (FIG. 5).

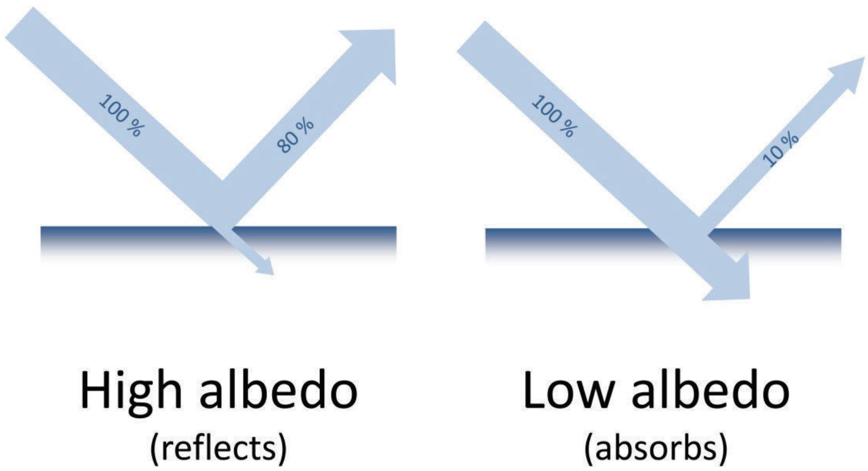

FIG. 5 - Example of the albedo principle (© EES project, RMAH Brussels).

The interactive ambient image calculated by the software of the PLD viewer mimics the surface's observed colour when illuminated under ambient lighting conditions, in this particular case it simulates the effect of all the dome LEDs lighting that surface simultaneously. The albedo and normal map are used to create an accurate, textured 3D model of the digitized object.

The ambient map serves as a comparison with (and alternative for) albedo, for inspection purposes for the users.

For the white light dome, the photometric stereo algorithm thus operates on a set of 260 images taken by the fixed camera – each with one LED activated – to produce the three output images, respectively containing the normal, the albedo and the ambient information for the observed object.

For the multispectral dome, the algorithm is subdivided for the different types of LEDs available, i.e. a similar algorithm operates on the IR, R, G, B and UV components. Alternatively, the formulation of photometric stereo can be reformulated to keep the normal constant. It is, however, interesting to observe that the normal information that is extracted clearly tends to get crisper for shorter wavelengths (UV) and shows a gradual sharpening up from IR to UV.

The physical phenomenon behind this is that electromagnetic energy at shorter wavelengths can detect smaller details (see FIG. 6 & 7).

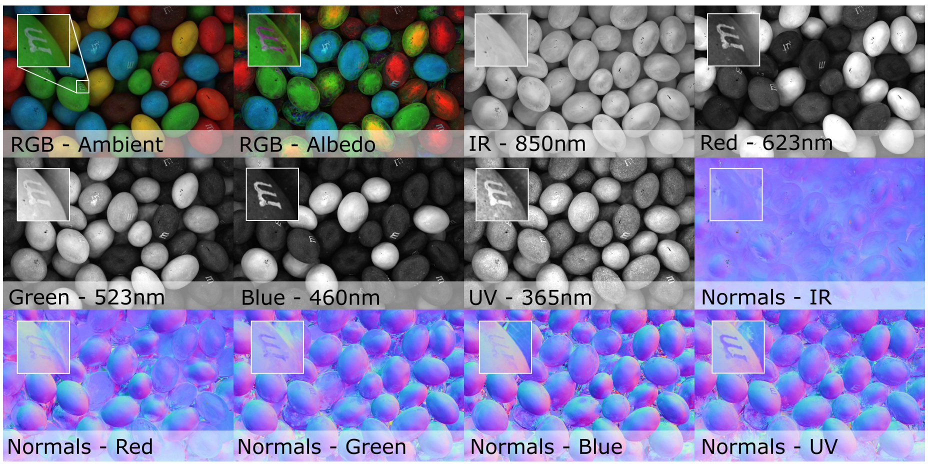

FIG. 6 - Overview of different visualizations of M&M's© by the PLD viewer software based on recordings by the MS Microdome, (©EES project & ESAT-VISICS, RMAH Brussels & KU Leuven).

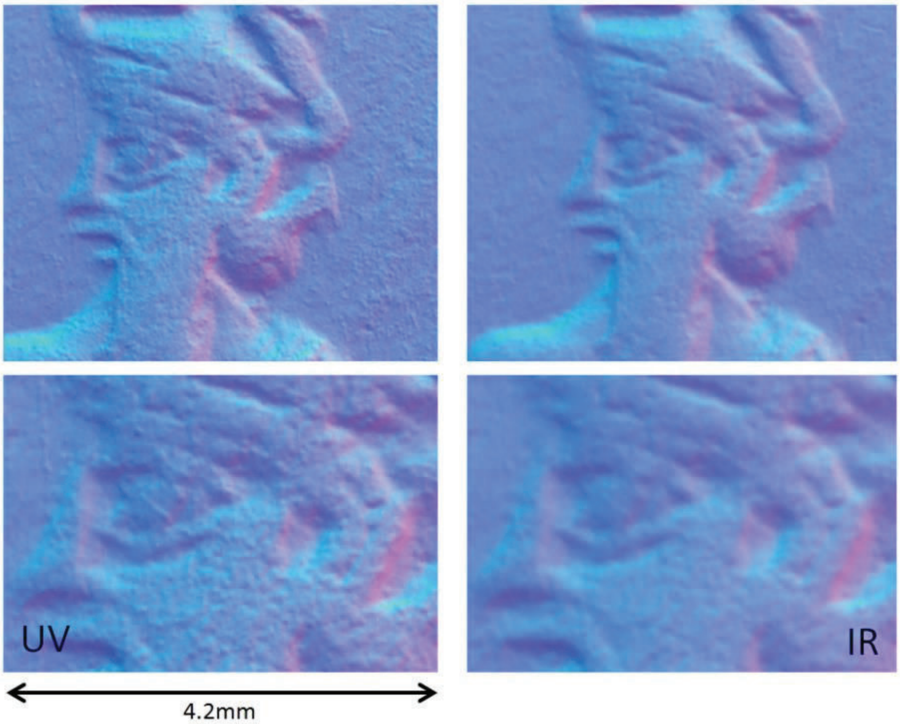

FIG. 7 - Difference in sharpness of the reconstructed UV and IR normal maps, for a detail of a seal impression on the reverse of cuneiform tablet NP 2 (© EES project & ESAT-VISICS, RMAH Brussels & KU Leuven).

5. Preliminary results

Art technical and conservation studies

Within the RICH project, techniques and conditions are explored on extremely delicate illuminations in medieval manuscripts. Condition and conservation assessments are combined and compared in the preliminary imaging protocol. In 2015, imaging with the MS Microdome focused on the "Anjou Bible", an illuminated manuscript created at the Royal Court of Naples for Robert I of Anjou by the illuminator Christophus Orimina (fl. 1230-1345) and his workshop around 1340 (KU Leuven, Maurits Sabbe Library, Ms 1). The leading illuminator was closely observing the techniques of Simone Martini (1284-1344), one of the most important panel painters in the south of Europe. Studies exploring the illuminating techniques (Watteeuw and Van Bos, 2010) revealed a complex and innovating palette for the first half of the 14th century (analyses by micro-XRF and Raman spectrometry, study in collaboration with the Royal Institute of Cultural Heritage, Brussels). Moreover, the imaging with the MS Microdome revealed new characteristics illustrating the topography, characteristics and the density of the thin pictorial layers on the parchment. Some initial observations about Fig. 8: the king's throne is presented before a drapery with his coat of arms (azure, *semé-de-lys or*, a label gules). The visualization in false colour revealed that for painting the blue background, two blue mineral colours are mixed; azurite and most probably ultramarine, not detectable with XRF, but colouring red in the false colour MS Microdome image (Fig. 8: C).

Fig. 8 - Bible of Anjou, Naples, 1340 (KU Leuven, MSB, Codex 1, folio 1 v.), detail. Conventional image (left), followed by three images with the MS Microdome (© RICH project & ESAT-VISICS, KU Leuven).

Under false colour IR, the gilded areas on the dalmatic of the king are showing micro-cracks in the gold leaf foil caused by micro-movement in the parchment support (Fig. 9: A). The added red transparent dots in glaze on the kings belt, depicting gems (rubies), are visible with the shaded UV filter. The transparent layer of paint, spread over the top of the opaque gold leaf, is visible as raised gritty spots (Fig. 9: B).

As regards the inscribed figurines from the EES project case study, the virtual representations enable researchers to study more than the faded inscriptions on them. To understand the construction process of these archaeological objects, their geometrical characteristics play a prominent role (Fig. 10).

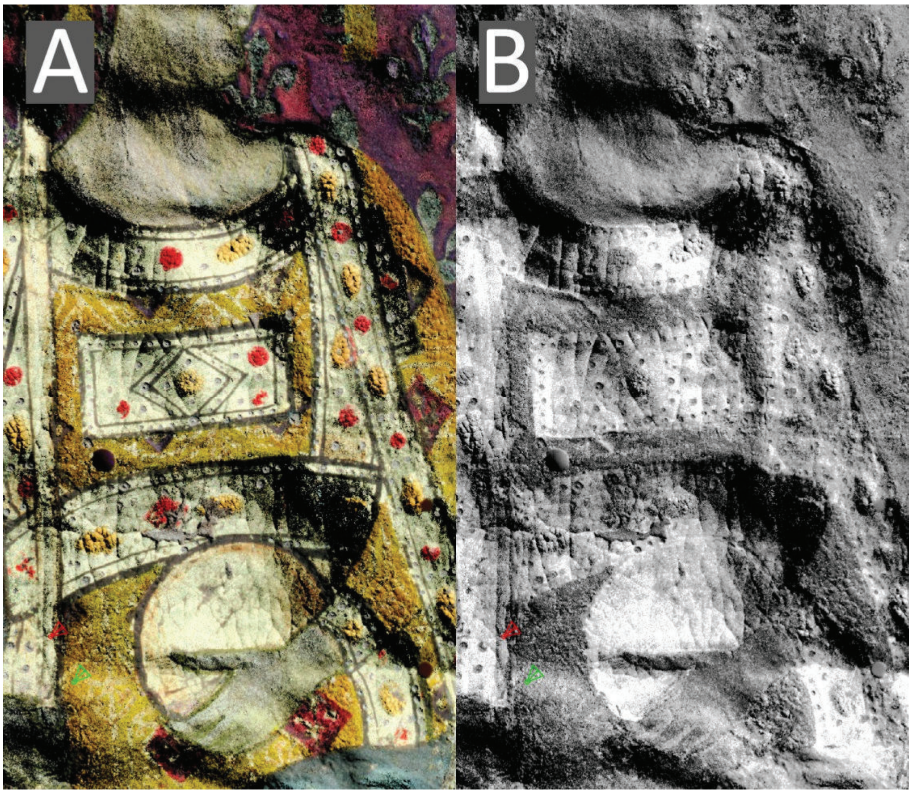

FIG. 9 - Bible of Anjou (detail), imaging with the MS Microdome. A) False Colour IR; B) shaded UV (© RICH project & ESAT-VISICS, KU Leuven).

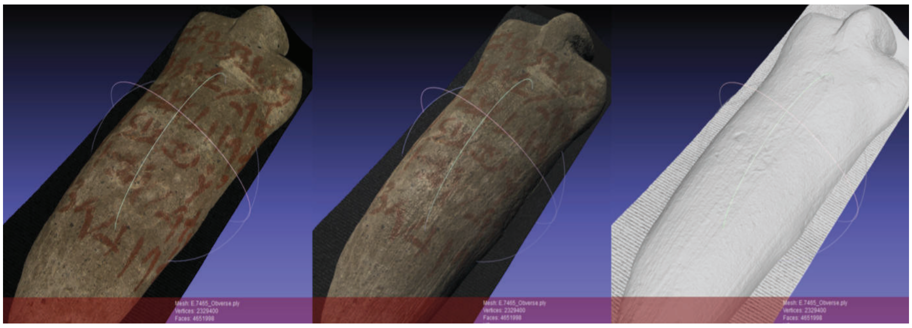

FIG. 10 - 3D images of E.7465 based on a dataset from the white light Minidome, visualised in MeshLab version 1.3.4BETA, left to right: renderings with colour, with shader PhongUntextured, without colour (© EES project & ESAT-VISICS, RMAH Brussels & KU Leuven).

As can be seen on a data acquisition by the white light Minidome of a fragmented figurine such information can be extracted and interactively visualized in the PLD viewer as well. On FIG. 11, the individual parallel strokes left by the manufacturer's fingers during the smoothening of the surface become visible when applying the appropriate enhancement filter and virtual relighting condition. The different directions and actions executed by the manufacturer can be followed and examined (marked with arrows in different colours on

FIG. 11). This shows that, even though the figurines were roughly modelled, a certain amount of attention was paid to the smoothening of the recto. The back side of the figurines tend to have a very rough surface, even when the inscriptions continued on that verso. This suggests that the appearance of the back was to be less important.

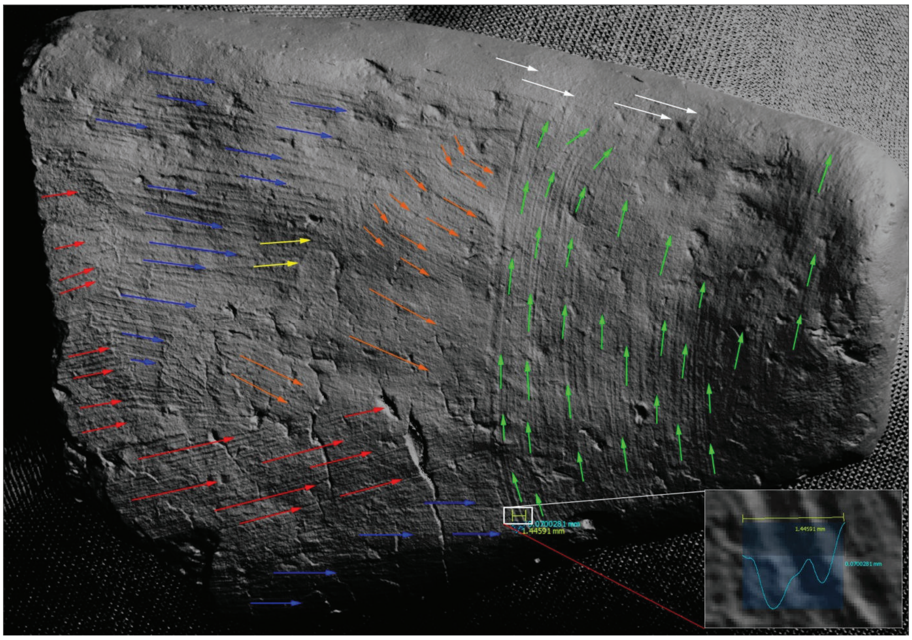

FIG. 11 - Directions of smoothing marks by fingers on the surface of E.7453 (recto), PLD viewer in shaded exaggerated mode (©EES project & ESAT-VISICS, RMAH Brussels & KU Leuven).

Throughout the EES project some other objects were also imaged for an art technical study with the MS Microdome, specifically to explore the system's potential with different kinds of materials. Tests were undertaken on a painted mummy portrait from Roman Egypt (one of the so-called Fayum portraits, see: Van der Perre and Hameeuw, 2015), but also on part of an Egyptian Late Period coffin (E. 2357) and on several ostraca (unpublished). Although these images require further research, preliminary results proved to be very promising.

Ancient inscriptions

One of the objectives of the EES project is to enhance the visibility of ink and pigment traces on (unbaked) three-dimensional clay objects

(FIG. 11). The figurines of our case study have been inscribed with two types of ink: red ochre and black ink. Literature studies (Danzing, 2010; Macfarlane, 2011, p.95) dealing with multispectral imaging – predominantly on parchment, papyri and ostraca – describe that black (carbon) inks tend to give the best results, whereas visualizing remnants of red ochre inks are often very problematic. The first tests with the MS Microdome, however, delivered some very promising results for the figurines inscribed with (red) ochre ink as well. When comparing the recordings from the first figurine processed with the MS Microdome with the original and conventional photographs, it was immediately clear that the legibility of the faded signs had improved significantly. It offered the ability to reconstruct parts of the inscription that were previously considered to be lost for good (FIG. 12).

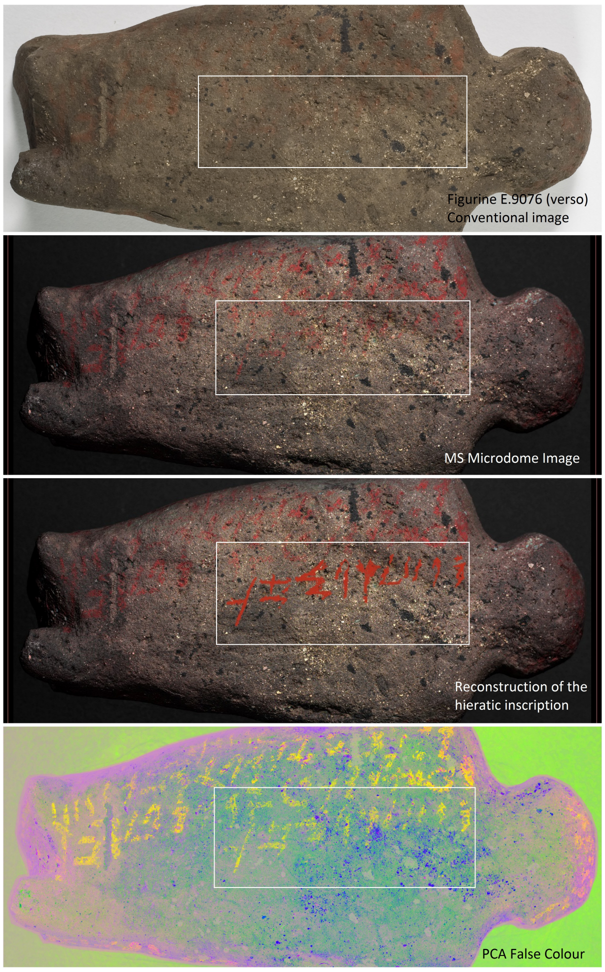

FIG. 12 - Reverse of an Egyptian execration figurine (RMAH E.9076), at the bottom a false colour PCA computation based on the images by the MS Microdome made with ImageJ software by R.B. Toth Associates and Equipoise Imaging (© EES Project & ESAT-VISICS, RMAH Brussels & KU Leuven).

In order to examine the quality, accuracy and adequateness of the multispectral component of the MS Microdome approach for the enhanced visualization of these inscriptions, the test artefacts were imaged and processed with both the MS Microdome and the spectral imaging tool by R.B. Toth Associates and Equipoise Imaging (Toth, 2015). The datasets of both acquisition systems were further processed using the custom ImageJ plug-ins by R.B Toth. The principal component analysis (PCA) false colour computations proved in both cases to give the best results (see also Baronti et al., 1997; France and Toth, 2011). As can be seen by examining and comparing the bottom representation on FIG. 12 and FIG. 13, their results are essentially comparable to ours.

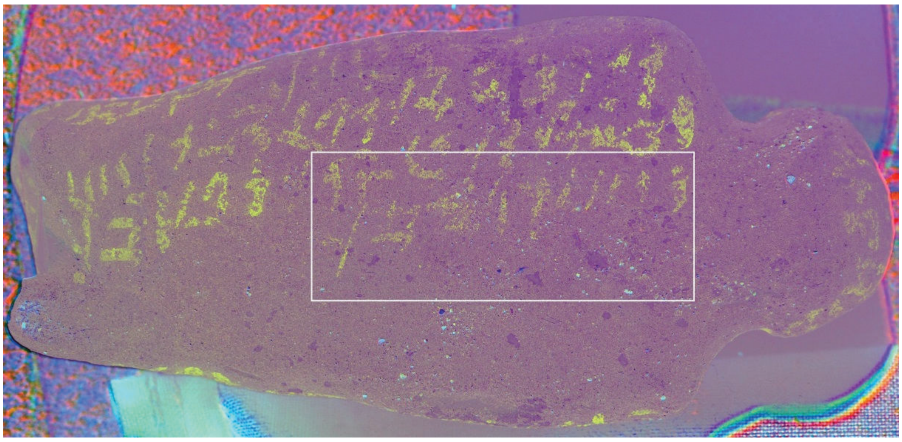

FIG. 13 - Reverse of RMAH E.9076, a false colour PCA based on both the images and the ImageJ computation by the Multispectral Imaging System by R.B. Toth Associates and Equipoise Imaging (© EES project, KU Leuven & R.B. Toth Associates and Equipoise Imaging).

6. Prospects

General prospects

In the next phases of development, we will consider more complicated material aspects for visualization such as BRDFs (Bidirectional Reflectance Distribution Functions). Dimensionality reduction and data mining techniques (e.g. PCA) will be considered to compress the data, and to automatically retrieve relevant content from the imagery. Corroborated by the current experiments, we foresee the possibility for adaptive photometric stereo, where the choice of lights can be controlled by the current observations.

Prospects for research on documentary heritage (RICH)

The ongoing studies on master drawings, prints, and medieval illuminations (the RICH, FINGERPRINT & ArtGarden Projects, 2016-2020) will explore and develop further the possibilities of the MS Microdome visualization. The combination with analytical micro-XRF mapping aims to benchmark reference data for inks, pigments and dyes captured in the false colour images. Standardization of these datasets aims to support non-invasive research and art technical interpretation on very difficult to access drawings and miniatures on paper and parchment. Apart from the variations of false colour images (combination of IR, R, G, B and UV images) further refined processing algorithms such as PCA and LDA (Linear Discriminants Analysis) will be added.

Prospects for research on archaeological artefacts (EES)

As stated above, several studies on the subject note that the best results are obtained for black inks, whereas red ochre inks are very problematic. Based on these observations, Egyptian execration figurines were expected to be a challenging case study given the fact that the vast majority bear red ochre ink inscriptions. Our tests, however, demonstrate the opposite: good results are obtained for red ochre ink, whereas black ink appears to be problematic. This contrasts strikingly with what is described in the literature, and thus calls for further research. An explanation may be found in the baked vs. unbaked condition of the medium. This will be further explored in upcoming final phases of both research projects.

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